Energy & Buildings 195 (2019) 161–167

Contents lists available at ScienceDirect

Energy & Buildings

journal homepage: www.elsevier.com/locate/enbuild

Energy and water efficiency in LEED: How well are LEED points linked to climate outcomes?

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ARTICLE INFO

Article history:
Received 30 August 2018
Revised 15 March 2019
Accepted 4 May 2019
Available online 4 May 2019

Keywords:
LEED
Green buildings
Water-energy nexus
Climate change

ABSTRACT

Buildings contribute to climate change and other environmental harms, largely through resource use. Reducing demand for resources like energy and water has become a major goal of sustainable building. Green building rating systems like Leadership in Energy and Environmental Design (LEED) present normative pathways to sustainability by rewarding certain types of activity deemed "sustainable." One challenge is that rewards are often delinked from environmental outcomes. We demonstrate this delinkage with a California case study that shows variability in the implied carbon dioxide avoided per LEED energy or water efficiency point can span multiple orders of magnitude, even for similar building contexts. This variability is related both to issues that LEED already considers, like building type, and to supply chain issues not directly considered in LEED, like the electricity fuel mix for buildings and water infrastructure. Additional variability comes from the structure of point allocation itself. We suggest that in order to fulfill LEED's goal of improving linkages between points and priority outcomes, future iterations can and should more directly account for interconnected systems and supply chains, with a particular focus on regional context. Such a change would extend existing practice for LEED Material and Resources credits and Regional Priority credits.

1. Introduction

Buildings consume large amounts of resources, which makes them highly relevant for environmental sustainability goals. Residential and commercial buildings consumed approximately 39 percent of the United States (US)' energy in 2017 [1]. Buildings also account for an estimated 12 percent of freshwater withdrawals in the US [2], and the built environment has dominated growth in water consumption over the past several decades [3]. The environmental impacts of this high level of resource consumption often include greenhouse gas (GHG) emissions, criteria pollutant emissions, and resource depletion, largely through direct and indirect energy use. For example, urban water systems can be energy intensive, contributing indirectly to GHG emissions depending on the nature of the energy supply [4]. Constructing, operating, and dismantling buildings sustainably can help mitigate these environmental disbenefits, which has fostered a proliferation of efforts to improve building sustainability [5]. In this context, we define buildings as sustainable if they deliver the services for which they are designed while ensuring that the environment is protected.

Green building rating systems are one approach to creating a shared understanding of what it means to achieve building sustainability. Against the backdrop of inherent value tradeoffs associated with sustainability goals [6], such rating systems make normative declarations about what it means for a building to be sustainable. This explicitness also makes rating systems relevant targets of critique and discussion related to sustainability metrics. Green building rating systems like the US Green Building Council (USGBC)'s Leadership in Energy and Environmental Design (LEED) not only systematically evaluate buildings' environmental impacts according to a predefined set of standards, they also drive behavior by people, organizations, and municipalities interested in pursuing sustainable infrastructure. For example, San Francisco requires all municipal construction projects larger than 10,000 gross square feet (ft^2; 929 m^2) to be LEED Gold certified [7]. LEED is not a static framework [8], and it has substantial reach: the rating system, which was established in 2000 and has certified over 92,000 commercial projects as of October 2017, is currently on its fourth version [9–11]. Continual improvements to systems like LEED can have a significant impact on the built environment over time.

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https://doi.org/10.1016/j.enbuild.2019.05.010
0378-7788/

One challenge with rating systems like LEED is that awarding points based on meeting a site-level target (e.g., "reduce indoor water use by X%") often fails to meaningfully reflect actual environmental impacts or capture relationships among systems. This critique is not new: there is some dispute as to whether LEED-certified buildings provide environmental benefits relative to non-certified buildings, which leads to questions about whether the rating system is rewarding site-level effort over environmental impact [12–18]. The LEED community has acknowledged shortcomings of LEED regarding verifiable environmental outcomes. Mahesh Ramanujam, President and CEO of the USGBC, has said that "What we have not done very well in the past is to actually integrate performance and outcomes-based data reporting into LEED certification" [19]. Developers receive points, and ultimately certification, even if the measures implemented do not result in environmental benefits [20].

Some evidence suggests that other green building rating systems are structurally more accommodating of linkages between outcomes and rewards [22], like the Building Research Establishment Environmental Assessment Method (BREEAM), developed in the United Kingdom [21], or the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE), developed in Japan [22]. For example, BREEAM awards points on an absolute basis (versus LEED's awarding based on a percentage reduction relative to a predefined baseline value) [23] and factors in local conditions when weighting its environmental section categories in an effort to allow communities to prioritize specific environmental concerns [22]. CASBEE compares building performance to environmental loads and provides parameters that enable locally informed weighting [22]. The German Passivhaus standards do not account for upstream environmental impacts of energy, but standards are based on absolute limits on energy consumption rather than percentage reductions relative to a baseline [24].

LEED v4 has attempted to rectify some of the problems with linkages between points and outcomes, introducing seven "Impact Categories" as system goals: "reverse contribution to global climate change," "enhance individual human health and well-being," "protect and restore water resources," "protect, enhance and restore biodiversity and ecosystem services," "promote sustainable and regenerative material resources cycles," "build a greener economy," and "enhance social equity, environmental justice, and community quality of life" [25]. Further, LEED v4 has stated a new focus on linking points with outcomes [26]. Despite these efforts, LEED v4 credits still often fail to account for systems-level issues like supply chains and interconnected infrastructures. In LEED v4, energy efficiency credits are not clearly linked to any of the Impact Categories: a point awarded for lower site energy use on a coal-dominated versus hydroelectricity-dominated grid, or for natural gas use versus electricity use, will have very different climate, human health, water resource, biodiversity, material resource, green economy, and social equity outcomes. Similarly, water efficiency credits do not explicitly account for issues like embedded energy or the source of the water, both of which have major implications for LEED Impact Category outcomes. Further, in both cases, equal points are not generally awarded for equal impact even at the site level [27].

As LEED continues to improve, we suggest that more explicit linkage between points and Impact Categories is both beneficial and achievable. Building designers often have enough knowledge of the local context of their project to directly address LEED Impact Categories, even when they do not have control over supply chains and system connections. In some cases, particularly regarding materials and resources credits, leveraging knowledge of the supply chain is already explicitly required [28]. Recognizing that information about supply chains is actually available can help LEED focus more directly on rewarding building decisions that promote underlying environmental goals. In this paper, we use a case study of LEED v4 in California to illustrate two points: first, a clear link can be drawn between the climate Impact Category and 26 points associated with energy and water efficiency credits; and second, even within a single state, supply chain and other regionalized variability contributes to highly variable environmental outcomes associated with a given LEED credit. Our case study joins others (e.g., [29]) in emphasizing that for an aspirationally global standard like LEED, prioritizing performance over credit compliance could improve outcomes.

1.1. Research focus and goals

This study focuses on the relationship between LEED v4's stated goal of "reversing contribution to climate change" [27] and LEED credits related to energy and water efficiency. We use a case study of buildings in California to demonstrate that supply chains and local variability have major implications for the climate impact of energy and water efficiency measures. Importantly, information about relevant factors like the carbon intensity of the local grid, total energy and water use, and other characteristics is available and could be used to improve the alignment between LEED credits and LEED goals. Creating a pathway for LEED to promote choices with greater climate mitigation impact instead of choices that meet credit metrics but are not meaningfully beneficial could improve the overall environmental performance of LEED buildings.

This study focuses on LEED v4, Building Design and Construction (BD+C), which applies to both new building construction and major renovation [27]. We specifically investigate the climate mitigation benefit per point allocated for water efficiency (Water Efficiency (WE) Credit: Indoor Water Use Reduction and WE Credit: Outdoor Water Use Reduction) and energy efficiency (Energy and Atmosphere (EA) Credit: Optimize Energy Performance) credits [27]. Each of these credit categories allocates points based on a specific percentage reduction in water or energy use, respectively. Using available information about baseline energy use and the water and energy systems that supply a building, estimated avoided GHG emissions can be calculated. Although resource conservation has value unrelated to GHGs, lowering GHG emissions is a major motivation for green building [30] and LEED specifically [25]. Particularly since GHG impact is relatively straightforward to calculate, it provides a clear example of how failure to directly engage integrated systems in LEED can lead to unbalanced crediting. Our ultimate research objective is to demonstrate that LEED's current energy and water efficiency credits have highly variable environmental outcomes even within a similar overall context, illustrated here with a case study of California. The variability in environmental outcomes from this case study indicates that LEED might consider how to better incorporate integrated systems, like energy and water, into its rating system framework.

1.2. Energy and water efficiency credits in LEED v4, BD+C

LEED v4, BD+C has four certification levels: Certified (40–49 points), Silver (50–59 points), Gold (60–79 points), and Platinum (80 points or more) [27]. LEED v4, BD+C awards up to 44 points in the Energy & Atmosphere (EA, 33 points) and Water Efficiency (WE, 11 points) credit categories, 40% of the total 110 possible points in the system.

The energy efficiency credit in LEED v4, BD+C can contribute substantially to a building's overall certification level, accounting for up to 18 points for new construction [27]. Efficiency strategies are numerous, from fundamental issues like building orientation and envelope design to nonstructural approaches like window or appliance choice. LEED v4 requires a minimum energy performance as a prerequisite, and points are not awarded for savings

above 50%. Energy efficiency points are allocated asymmetrically, with one point for 6% reduction versus baseline, one point for each subsequent 2% reduction up to 26%, one point for each subsequent 3% reduction up to 38%, and then one point for each subsequent 4% reduction up to 50%. This asymmetry, along with the cap on points awarded beyond 50% reductions, appears to be designed to prevent builders from focusing on energy efficiency to the exclusion of other criteria. It is notable, however, that the credit system explicitly delinks points from performance outcomes by not offering a flat reward for ostensibly equal impact. Also, the energy efficiency credit does not distinguish types of energy use, like electricity versus non-electric uses.

The water efficiency credits in LEED v4, BD+C focus separately on reducing indoor and outdoor water consumption in buildings, requiring prerequisite baseline achievement for each [27]. Beyond these prerequisites, LEED v4 awards points for water efficiency in four categories: Indoor Water Use Reduction, Outdoor Water Use Reduction, Cooling Tower Water Use, and Water Metering [27]. This work addresses only the Indoor and Outdoor water use reduction credits, which account for a combined maximum of 8 points. For Indoor Water Use Reduction, one point is awarded if the project achieves a 25% reduction in consumption relative to the baseline, with an additional point awarded for each incremental 5% reduction, up to a maximum of 6 points for a 50% reduction [27]. The main indoor water use reduction method is to upgrade baseline appliances, fittings, and fixtures to more water efficient products that are certified by either ENERGY STAR® or WaterSense [27]. For outdoor water use, one point is awarded for a 50% reduction in outdoor water use, while two points are awarded for 100% reduction (i.e., elimination) [27]. Outdoor water reduction methods include limiting the amount of irrigated landscape, switching to water efficient plant species and landcover, improving irrigation efficiency, using alternative water sources, and completely eliminating an irrigation system [27]. As currently implemented, LEED does not account for differentiated environmental impacts of water based on issues like water source or embedded energy, among others. The distinction between indoor and outdoor water use, however, does implicitly reflect that the environmental impacts of these uses are distinct. For example, even when both indoor and outdoor water supplies are potable, outdoor water use does not typically need environmentally intensive wastewater treatment.

1.3. Energy, water, and greenhouse gas emissions

This research investigates the relationship between the environmental outcome of avoided GHG emissions and the rating system outcomes of awarded energy and water efficiency points in LEED v4 BD+C using California as a case study. Our primary goal is to characterize the relationship between avoided climate impact in the form of CO_2 emissions and awarded credit in the form of LEED points, in part because “more goal-oriented credits” is an explicit design goal for LEED v4 [26]. We ask: does each point awarded for energy and water efficiency measures deliver a similar climate benefit? We specifically look at CO_2 emissions associated with avoided energy use for building energy and water systems (aligned with the “reverse contribution to global climate change” Impact Category [25]), but a similar approach to investigating other USGBC Impact Categories could also be taken.

Understanding the linkage between energy and water consumption and its effect on GHG emissions is crucial for analyzing the efficacy of building rating systems at improving building-related environmental outcomes. Energy is the largest contributor to US GHG, and energy efficiency is an important pathway to GHG savings [31]. The GHG impact of energy efficiency is governed by the carbon intensity of the energy supply. Energy systems produce GHG emissions largely in the form of carbon dioxide (CO_2) from fossil fuel combustion and methane (CH_4) leakage from natural gas and coal systems [32]. For energy used in buildings, these emissions are typically associated with coal and natural gas burned in power plants and natural gas burned inside buildings for cooking and heating. Energy-related GHG intensity can be calculated at multiple scales, including fuel [33], state [34], utility [35], and combinations of power plants [36].

Similarly, water usage reductions can be an important source of GHG emission reductions because of the GHGs embedded in the energy expended to obtain, deliver, treat, and condition water. An estimated 8% of US primary energy consumption is used for direct water services [4]. Water systems demand energy both outside the building (for acquisition, treatment, and transportation) and inside the building (for heating and sometimes on-site treatment). Indoor water use also generally induces demand for wastewater treatment, which varies in energy intensity based on level of treatment [37]. Data on energy and carbon intensity of water and wastewater systems are increasingly available or estimable [38–40].

1.4. Case study

We select California as a case study for several reasons. First, the state’s climatic diversity affects energy and water demand in a given building. California has sixteen distinct climate zones, with weather and temperature patterns unique to each zone [41]. Each zone has a corresponding energy budget which is used to determine a building’s maximum allowable energy use under California’s Title 24 building code [42]. Regarding climatic variation and water demand, each of the zones exhibits particular precipitation patterns that affect outdoor water requirements. Given that LEED awards points for energy and water savings as percentage reductions, the overall impact varies by the amount of energy and water used in a baseline building. Second, California has multiple large utility districts with differing energy profiles. For example, the 2016 electricity mix for San Diego Gas and Electric (SDG&E) includes 43% from eligible renewable or zero CO_{-2} emission resources compared to Pacific Gas and Electric’s (PG&E) 69% [43]. Third, GHG-relevant interconnections between California’s energy and water systems enable a close look at the influence of these connections. Specifically, some of California’s water supplies are much more energy intensive than others: Stokes-Draut et al. estimate the energy intensity of the Southern Coast hydrologic region’s water supply to be more than six times that of the Northern Coast hydrologic region’s [37]. The energy intensity disparity is due to the large amount of energy used to transfer water from the northern regions to the drier central and southern regions of the state to meet demand in population centers like Los Angeles, Orange County, and the Inland Empire [37]. As with energy, the embedded GHGs in water vary given the variable carbon intensity of the relevant energy supply.

This work investigates the climate impact of LEED v4, BD+C energy and water efficiency credits for three building types (single-family, multi-family, and large office) in five cities across California (Sacramento, Hayward, Modesto, Santa Ana, and San Diego). Baseline energy and water budgets for the three building types are developed using academic and government sources [44–47]. GHG emissions for each baseline are estimated using data on each city’s electricity utility [35] and hydrologic region (Stokes–Draut, in preparation). Then, we estimate avoided CO_2 emissions per point for each building type and city. One priority is to demonstrate that avoided climate impact per point can be approximated using available data and relatively simple calculations. LEED could put greater emphasis on the environmental context of site-level resource savings without imposing an unreasonable burden on users.

2. Calculations

Specific methods for modeling GHG savings associated with LEED v4, BD+C EA and WE credits are found in the Supplemental Information (SI), which includes Tables A1–A10 in addition to supplemental text. Broadly, our modeling approach is as follows. First, we establish baseline energy and water usage for each of our three building types (single family residential, multi-family high rise, and large office) in each of five locations (from north to south, Sacramento, Hayward, Modesto, Santa Ana, San Diego). These building types are representative of those projected to constitute the largest volume of construction in California by 2020 [44]. Baseline site energy use (electricity and natural gas) for each of the 15 building-location combinations is derived from [44] (Tables A1 and A2). Baseline indoor and outdoor water volume use for each building-location combination is established using California's Title 24 (the minimum required water efficiency standards in California) and Model Water Efficient Landscape Ordinance (MWELO). The indoor water volume does not include water used in industrial processes, such as cooling towers. On-site water reuse measures are also not analyzed. Occupancy, application-specific flow rates, end-use statistics, and irrigation demand (Tables A1 and A4-A8) are used to calculate the indoor and outdoor water baseline volume use for each building type. We do not explicitly address LEED energy and water prerequisites because these are met through California's building code [48].

Second, we calculate embodied CO_2 emissions per unit of energy and water use. Emissions associated with building energy use are estimated as direct combustion-related carbon dioxide emissions factors for each resource (Table A3) [35]. Note that life cycle GHG emissions are higher, especially due to methane leakage in the natural gas supply chain [49]. Similarly, indoor and outdoor water use climate intensity is estimated using water and wastewater carbon dioxide emissions factors (Tables A9, A10) (Stokes–Draut, in preparation).

Finally, we link embodied CO_2 estimates to LEED points. We use Step (1) to estimate the total amount of energy or water saved per point, as points are allocated based on percentage savings of baseline use, then multiply by factors from Step (2) to estimate avoided CO_2 per point.

3. Results and discussion

Fig. 1 displays the range of estimated CO_2 emissions avoided per point awarded for energy or water efficiency credits in LEED v4, BD+C for single-family, multi-family, and large office buildings in our five California cities of interest. Fig. 1 reflects 930 modeled LEED v4, BD+C points: 3 building types × 5 locations × (2 outdoor water efficiency points + 6 indoor water efficiency points + 18 electricity-only energy efficiency points + 18 natural gas-only energy efficiency points + 18 combination electricity and natural gas energy efficiency points) (see SI for details).

The majority of modeled LEED water and energy efficiency points (~85%) are expected to result in between 0 and 0.5 kg of avoided CO_2 per square meter of floor area (m^2) per year. Unsurprisingly, given the more direct link to combustion, energy efficiency points result in more expected CO_2 mitigation than water efficiency points. Given water efficiency's more direct link to another LEED v4 Impact Category, "protect and restore water resources," the much different CO_2 profile is likely an acceptable tradeoff when points are being mapped to impacts, but designers should confirm that simply reducing building-scale water use contributes to protection and restoration of the resource in the intended manner.

Differences in CO_2 avoided across credit categories is likely mitigated by links to other impact categories, but how consistently do points reward impact within credit categories? Figs. 2 and 3 show the distribution of avoided kg CO_2/m^2/yr/point for energy (Fig. 2) and water (Fig. 3) efficiency credits based on several different characteristics: cumulative resource savings (Panel A), building type (Panel B), city (Panel C), and type of resource saved (e.g., indoor versus outdoor water) (Panel D). Most notably, the range of avoided CO_2 per point spans about an order of magnitude for all investigated categories, despite normalization to building floor area. That is, even within a single credit category and single impact category, the link between points and outcomes is weak.

Figs. 2 and 3 suggest several relevant conclusions. First, variability within any given category is high. For energy efficiency, CO_2 emissions avoided per point span about an order of magnitude in each investigated category. For water efficiency, variability is up to four orders of magnitude, largely because outdoor water use points have almost no impact on CO_2 emissions given no need for wastewater treatment. Overall, the CO_2 avoided per point varies by a factor of about 100 for indoor water efficiency and by about 6600 for outdoor water efficiency.

One important note about variability is that some of it is due directly to the structure of LEED points (Figs. 2a and 3a). As Figs. 2a and 3a show, awarding points for unequal resource use reduction intervals (i.e., 6%, then 2%, 3%, or 4% reductions for energy and 25%, then 5% for indoor water use) leads to substantial variability in avoided GHGs per point. Outdoor water use points are awarded for 50% steps in reduction, which eliminates variability associated purely with point allocation structure. If LEED values outcome-linked points, this allocation is a particularly good target for change because it requires no additional information from projects.

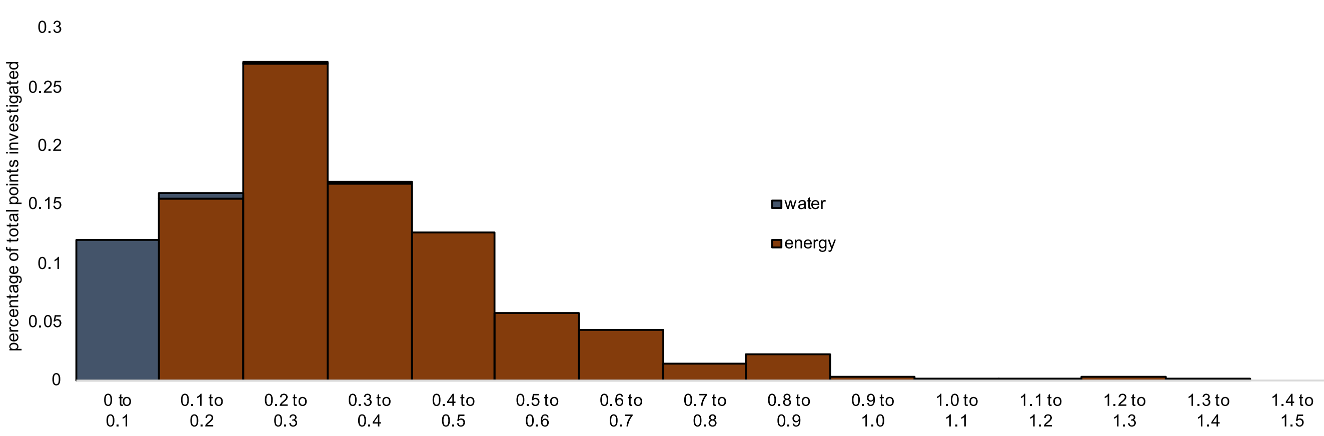

Fig. 1. Distribution of direct CO_2 emissions avoided per LEED v4 BD+C energy or water efficiency point in study, kg/m^2/yr/point.

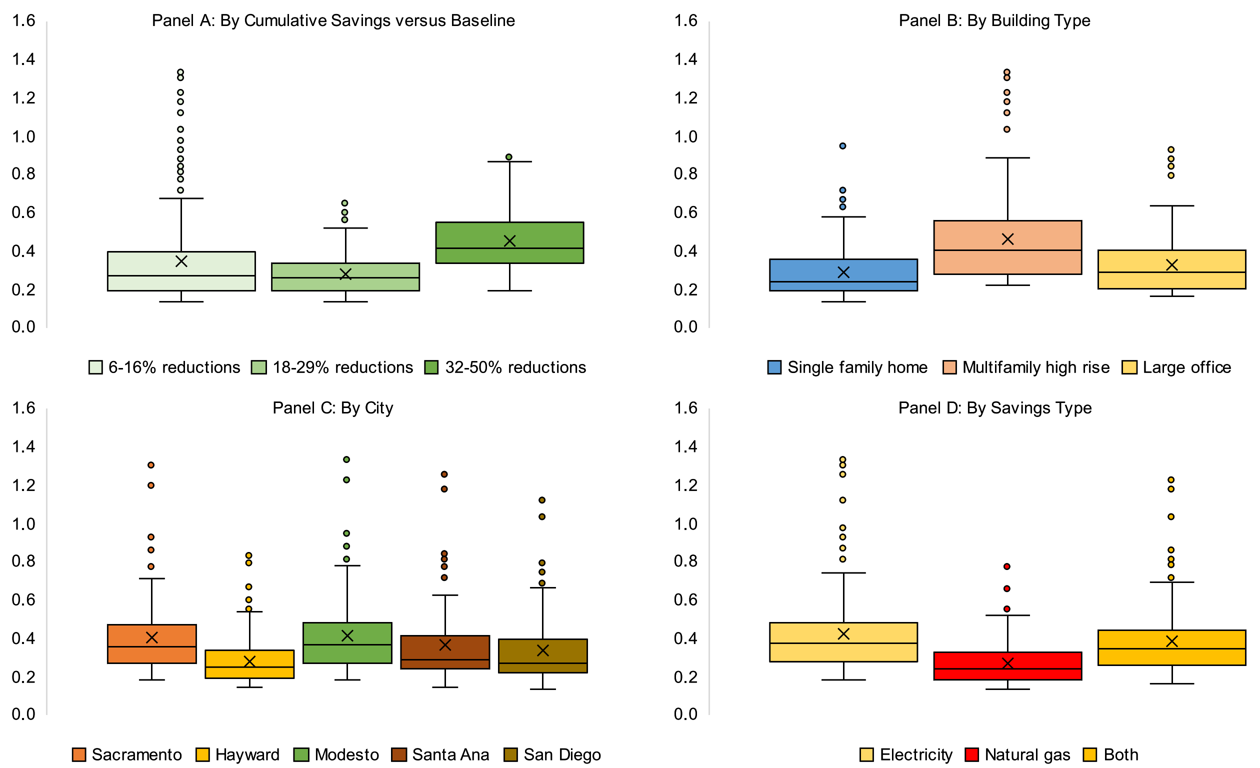

Fig. 2. Variation in CO_2 emissions offset per LEED v4 energy efficiency point in study, kg/m^2/yr/point, by characteristic *(note: vertical scale 4x Fig. 3)*.

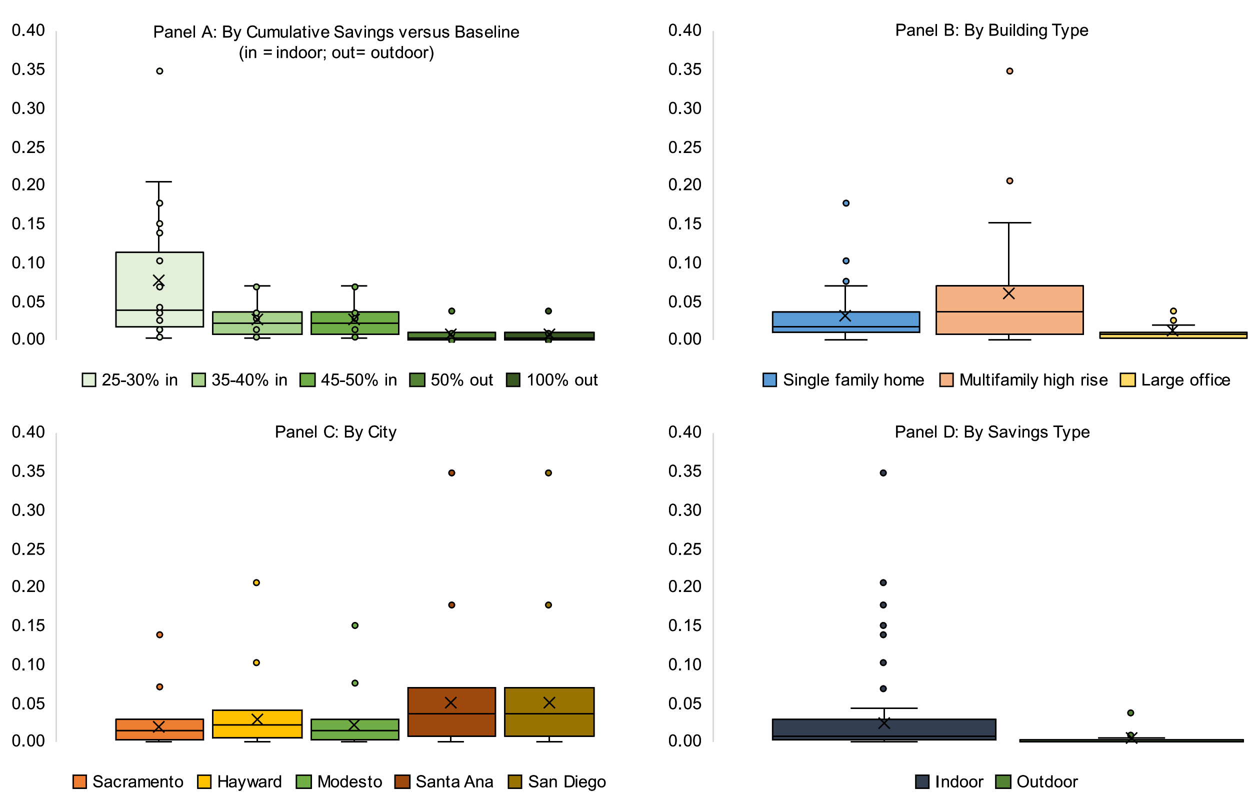

Fig. 3. Variation in CO_2 emissions offset per LEED v4 water efficiency point in study, kg/m^2/yr/point, by characteristic *(note: vertical scale ¼ of Fig. 2)*.

LEED v4, BD+C does already distinguish between some relevant characteristics, like building type (Figs. 2b and 3b) and water use category (Fig. 3d). For example, multifamily high rise buildings generally show greater potential for CO_2 avoidance per point in part because baseline usage per square foot is higher for these buildings versus single family homes or large offices—the fact that they are subject to different certification standards is appropriate. Fig. 2d suggests that just as indoor and outdoor water use is considered separately in LEED WE, likely because of the differential impact of these use types (e.g., Fig. 3d), differential impact from electricity and natural gas use should potentially be considered in future iterations of LEED EA credits. We note that our illustrative use of direct CO_2 emissions here excludes the potential impact of methane leakage from the natural gas system [49]: in some cases, natural gas use reductions result in more significant avoidance of GHGs and other emissions than electricity use reductions.

Location also affects CO_2 avoidance per point (Figs. 2c and 3c). This variation is largely due to supply chain differences in energy and water provision, which in turn are often location-based. For example, electricity utilities serving specific areas have different generation portfolios with variable environmental impact, and water might be from an energy-intensive groundwater source or a largely gravity-fed conveyance system from a surface water supply–implying that both energy intensity and the energy's carbon profile can vary substantially. Even if supply chains are identical, climate factors influence the amount of energy or water demanded in a given region, e.g., for air conditioning or summer irrigation.

LEED already accounts for differentiated impact based on both supply chains and location elsewhere in its standards, so expanding that systems-based view to credit categories like EA and WE is likely reasonable for future iterations. For example, the Materials and Resource Credit category acknowledges the environmental impact of building material supply chains and rewards efforts for trying to make the material supply chain more sustainable [28]. LEED has also included some acknowledgement of location-specific outcomes through Regional Priority Credits, which are “credits identified by the USGBC Regional Councils and Chapters as having additional regional environmental importance” [27,50]. Currently, up to four location-specific points can be earned. Given the importance of location and regional supply chains, future iterations of LEED would likely better reflect environmental performance by increasing incentives to be location-conscious. The Regional Priority concept could easily be extended to a more outcomes-driven point system that reflects local system conditions like the carbon intensity of energy and the energy intensity of water.

As with many theoretical studies, data sources used for this analysis introduce uncertainty. For example, energy usage data are based on simulations for prototypical buildings [44] and therefore might not capture relevant dynamics related to system losses and occupant behavior. Similarly, water usage data are compiled from sources with different vintage ([46,47] and Stokes–Draut, in preparation), which could affect our estimates. Carbon intensities used here are not life cycle factors, and they exclude important contributors to climate pollution like methane leakage. These uncertainties do not affect the broader conclusion that although LEED points do not equally reward equal impact mitigation, relatively straightforward changes to crediting could reconcile these differences. That is, impacts like expected climate change pollution mitigation can be calculated.

4. Conclusion

LEED credits are sometimes critiqued for not directly corresponding to a measurable environmental goal. Our case study of the link between LEED v4, BD+C energy and water efficiency credits and the LEED climate Impact Category for buildings in California emphasizes that even within a single state, local variability in systems-level contexts like energy supply chains and interconnected infrastructures leads to orders of magnitude differences in climate outcomes per LEED point. This finding suggests that as LEED continues to develop, there is room for improvement in rationalizing points with outcomes. Perhaps more importantly, our research demonstrates that at least for climate, and likely for other Impact Categories, more coherence between points and outcomes can be achieved with relatively simple steps. Notably, one contributor to variability is that LEED does not award equal points for equal impact in the energy and water impact categories. More generally, though, avoided climate impact per point can be approximated using available data and relatively simple calculations, as we demonstrate using data from California.

We recommend that in future iterations, LEED should directly map points to underlying sustainability goals; account for the fact that some data (e.g., energy system fuel mix) are likely to both affect sustainability outcomes and be relatively easy to obtain during project design; and carefully consider sustainability goals and Impact Categories in allocating points across integrated systems. As a major and widely-recognized green building rating system that demonstrably affects infrastructural outcomes and sustainability discourse, LEED can promote more sustainable outcomes by carefully addressing inter-system integration. Continued investigation into interconnected infrastructures and building systems, including the energy-water-climate nexus in buildings, can facilitate solutions for mitigating negative environmental outcomes and help move us toward a more sustainable building stock.

Conflict of interest

None.

Acknowledgments

Thank you to Jennifer Stokes–Draut for use of her carbon intensity factors for California water systems. Thank you also to three anonymous reviewers for their comments. This work did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.enbuild.2019.05.010.

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